Spatial Relationship Between Particulate Matter (2.5) and Respiratory Health in North America

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ABSTRACT

This study examines the spatial relationship between Particulate Matter (PM) 2.5 concentrations and respiratory health issues, including asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer, across North America. By analyzing regional variations in North America, the research identifies significant correlations between elevated PM 2.5 levels and increased rates of respiratory conditions, particularly in vulnerable populations under 18 and above 65. The findings highlight regions in North America where air pollution is most strongly linked to adverse respiratory health outcomes, emphasizing the need for targeted public health interventions.

KEYWORDS

Particulate Matter (PM) 2.5, Respiratory Health, Asthma, Chronic Obstructive Pulmonary Disease (COPD), Lung Cancer, North America, Air Pollution, Public Health, Spatial Analysis, Vulnerable Populations.

1 INTRODUCTION

Air pollution, particularly particulate matter (PM 2.5), has been recognized as a significant threat to public health. PM 2.5 refers to airborne particles with diameters of less than 2.5 micrometers, which are small enough to penetrate deep into the lungs and enter the bloodstream, leading to a range of health problems. Among the most severe outcomes associated with PM 2.5 exposure are respiratory conditions such as asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer. These conditions place a heavy burden on healthcare systems and majorly affect vulnerable populations, especially children under 18 and adults over 65.

The geographical correlation between PM 2.5 concentrations and the incidence of respiratory illness in North America is examined in this study. Understanding this correlation is essential for pinpointing high-risk regions and executing focused public health initiatives. Although the negative health impacts of particulate matter 2.5 in the air have been studied before, this study attempts to give a thorough spatial analysis by looking at the geographic patterns of PM 2.5 and hotspots for respiratory diseases. The study identifies areas where the effects of air pollution on respiratory health are most noticeable by mapping and examining these patterns.

2 PROBLEM DOMAIN

Air pollution, particularly fine particulate matter (PM 2.5), is a significant public health threat in North America, especially in the eastern and Midwest regions of the United States. PM 2.5 particles are small enough to be inhaled deeply into the lungs, leading to serious respiratory conditions such as asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer. These health impacts are more pronounced in vulnerable populations, including children under 18 and adults over 65, who are particularly sensitive to the adverse effects of air pollution.

Developing focused treatments to lower exposure and improve health outcomes especially for those in the age groups most affected requires an understanding of the spatial association between PM 2.5 levels and respiratory conditions in this area.

3 LITERATURE REVIEW

The relationship between air pollution, particularly fine particulate matter (PM 2.5), and respiratory health is well established. PM 2.5 particles are small enough to be inhaled into the lungs, leading to respiratory conditions such as asthma. Vulnerable populations, including children are especially susceptible to the adverse effects of PM 2.5 exposure [1].

Asthma has been closely linked with increased PM 2.5 levels. Guarnieri and Balmes (2014) found that exposure to air pollution significantly worsens asthma symptoms and can trigger attacks, particularly in areas with sustained high pollution [1]. Similarly, Schraufnagel et al (2019) note that long-term exposure to PM 2.5 is associated with increased severity of respiratory illness symptoms [2].

COPD and lung cancer are also influenced by PM 2.5 exposure. Pope et al. (2002) demonstrated that long-term exposure to fine particulate matter increases mortality rates from COPD and contributes to lung cancer risk, even among non-smokers [3]. These findings emphasize the critical health impacts of air pollution.

Geospatial mapping is an effective tool for visualizing the relationship between air pollution and respiratory illnesses. In a study by Shah et al. (2023), geospatial techniques were used to highlight areas with high PM2.5 levels in an urban slum, showing a clear concentration of respiratory symptoms in those regions. This mapping approach helps identify pollution hotspots and their health impacts, emphasizing the need for targeted interventions in affected areas.[4]. Geospatial Hotspot analysis identified a strong link between lung cancer incidence and PM2.5 levels in Eastern Thailand. People over 50 were most affected which links to this research of correlation between vulnerable population, lung cancer incidents and PM 2.5 [5].

3.1 Research Questions

- What is the spatial distribution of asthma, Chronic Obstructive Pulmonary Disease, and lung cancer cases in relation to PM 2.5 concentrations across different regions in the eastern United States?

- How does long-term exposure to high levels of PM 2.5 impact the prevalence and severity of asthma in vulnerable populations, particularly children under 18 and adults over 65?
- What are the geographic hotspots of PM 2.5-related respiratory diseases, and how do they correlate with socioeconomic in North America?
- How can geospatial analysis be used to identify regions where PM 2.5 reduction could have the greatest positive impact on public health?

4 OBJECTIVES

The primary goal of this research is to investigate the spatial relationship between PM 2.5 concentrations and respiratory health conditions, particularly asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer, across North America. The objectives are:

- To map and analyze the distribution of PM 2.5 levels across North America using geospatial analysis.
- To identify and explore geographical clusters of respiratory diseases, including asthma, COPD, and lung cancer, in relation to PM 2.5 concentrations.
- To evaluate the statistical correlation between PM 2.5 exposure and the prevalence of respiratory health issues, with a focus on vulnerable populations (children under 18 and adults over 65).

5 METHODOLOGY

This study employs ArcGIS Pro to investigate the spatial relationship between PM 2.5 concentrations and respiratory health conditions, such as asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer, across North America. The methodology begins with the collection and preparation of relevant datasets, including air pollution levels, health data, and demographic information focusing on vulnerable populations (under 18 and above 65). These datasets are imported into ArcGIS Pro as feature classes, ensuring consistent georeferencing.

Key spatial analysis techniques are applied, starting with Hotspot Analysis using the Getis-Ord Gi* tool to identify statistically significant clusters of high or low incidences of respiratory diseases. In addition, Select by Attributes is used to focus on specific regions or demographic groups for detailed analysis. Graduated color mapping is employed to visualize the spatial distribution of PM 2.5 levels and health outcomes, using color gradients to represent varying concentrations. Finally, multiple map layouts are created to provide clear and meaningful visual representations of the data, with legends and symbols that highlight areas requiring further attention. This methodology enables a comprehensive spatial analysis of how air pollution impacts respiratory health across North America.

5.1 Datasets

Several datasets were utilized to analyze the spatial relationship between PM 2.5 concentrations and respiratory health conditions across North America:

- **Asthma and COPD** : The asthma and COPD data were derived from the PLACES: County Data - GIS Friendly Format (2024 release) from the Centers for Disease Control and Prevention (CDC) . This dataset provides state-level,tracts-level, county-level data on health conditions and is formatted for easy integration with GIS applications [6].
- **Particulate Matter (PM 2.5)** : The PM 2.5 concentration data was confirmed using two different sources. The primary dataset was accessed via the ArcGIS Online portal [7] and cross-referenced with the World Air Quality Index by City and Coordinates dataset available on Kaggle to ensure accuracy [8].
- **Population Data:**: The population data, particularly focusing on vulnerable groups (under 18 and over 65), was sourced from ArcGIS Online [9].
- **Lung Cancer Incidence Rates**: Data on lung cancer incidence rates was obtained from the ArcGIS Online portal , which provides geographic information on cancer occurrences across North America [10].

6 RESULTS

6.1 Particulate Matter (PM 2.5) Levels

The PM 2.5 Distribution Map (Figure 1) shows regions with high levels of particulate matter in the eastern and Midwestern United States, aligning with the respiratory disease hotspots identified. Regions such as Ohio, Pennsylvania, and Kentucky have average PM 2.5 concentrations above 14 micrograms per cubic meter, which exceeds the recommended safety thresholds for air quality.

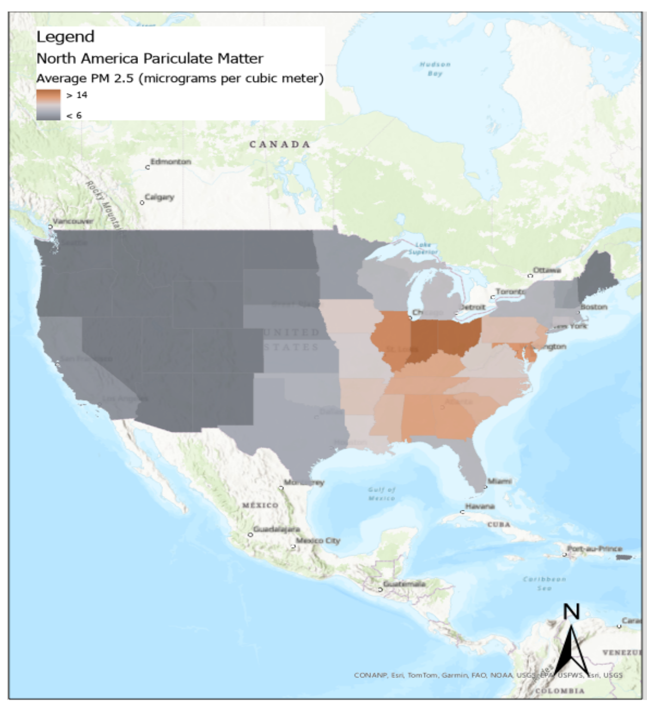

Figure 1: Particulate Matter (2.5) in North America.

6.2 Air Quality Index Across North America

The Air Quality Index (AQI) map (Figure 2) visualizes varying air quality levels across North America. Regions with the modertae air quality, marked in red, coincide with areas of high respiratory disease rates, reinforcing the direct impact of poor air quality on public health.

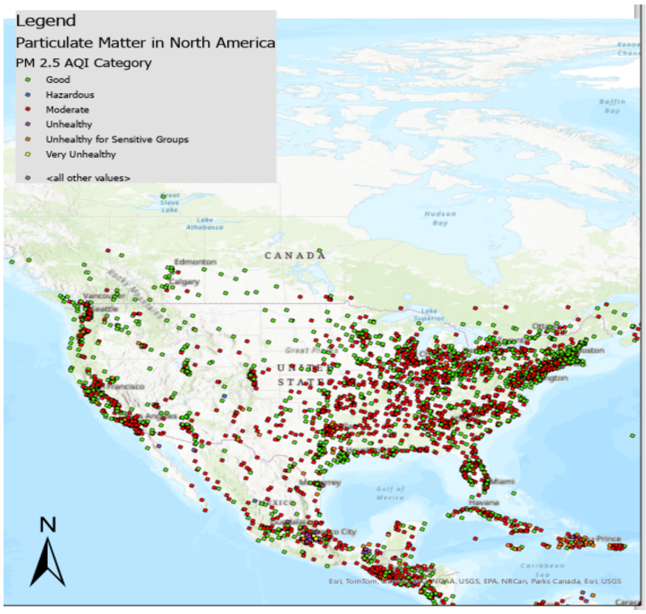

Figure 2: Particulate Matter 2.5 category data in North America

6.3 Lung Cancer Incidence Rates:

The comparison between the PM 2.5 distribution and lung cancer incidence rates in the Midwest and eastern United States reveals a notable spatial correlation. As shown in the PM 2.5 map (Figure 1), regions such as Ohio, Pennsylvania, Kentucky, and West Virginia exhibit elevated PM 2.5 levels, with average concentrations exceeding 14 micrograms per cubic meter, surpassing the recommended safety thresholds.

In the lung cancer map (Figure 3), these same regions also display the darkest shades, representing the highest age-adjusted lung cancer incidence rates. Kentucky, in particular, stands out with the highest lung cancer rates, closely followed by West Virginia and parts of Indiana and Ohio. These areas also correlate strongly with the high particulate matter concentrations visible in the PM 2.5 map.

The correlation between PM 2.5 levels and lung cancer rates in the Midwest and eastern United States suggests a direct relationship where higher pollution levels contribute to higher lung cancer incidence. This pattern is consistent with research linking long-term exposure to fine particulate matter with increased risks of lung cancer. The strong presence of both high PM 2.5 levels and elevated lung cancer rates in these regions highlights the need for stricter air quality controls to protect public health.

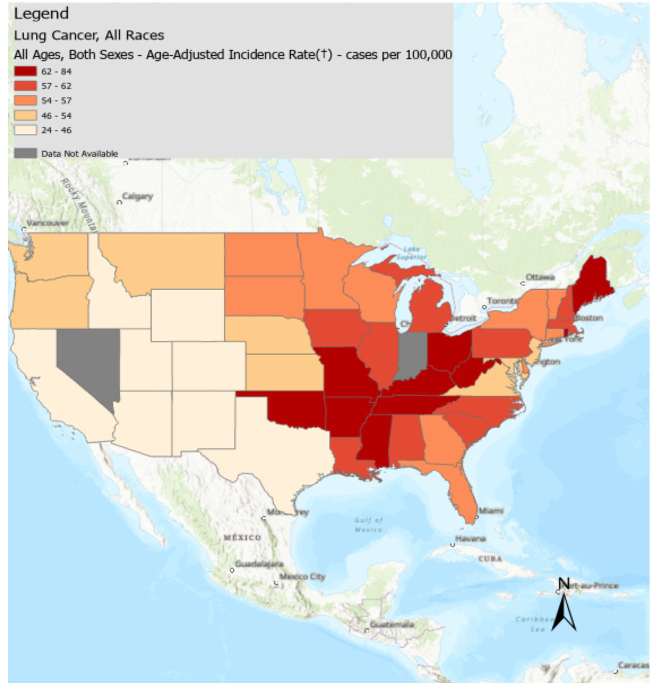

Figure 3: Lung Cancer Cases in North America

6.4 Chronic Obstructive Pulmonary Disease (COPD) Hotspots

The COPD Hotspots Map (Fig 4) reveals a clear concentration of Chronic Obstructive Pulmonary Disease (COPD) cases in the southeastern and Midwestern United States. The most intense hotspots, represented by red clusters with 99% confidence, are particularly visible in states such as Kentucky, West Virginia, and parts of Tennessee and Ohio. These areas are closely aligned with regions that experience elevated PM 2.5 levels, suggesting a strong correlation between air pollution and the prevalence of COPD. The clustering of COPD hotspots in these regions points to the severe public health impact of long-term exposure to air pollution, especially fine particulate matter.

Conversely, the western United States is dominated by cold spots (blue areas), indicating lower COPD detection rates. These areas coincide with regions that have lower PM 2.5 concentrations, reinforcing the inverse relationship between air quality and COPD prevalence. The Midwest and parts of the eastern U.S., with significant COPD clusters, are particularly affected by higher pollution levels, underscoring the need for targeted air quality improvements and healthcare interventions in these regions.

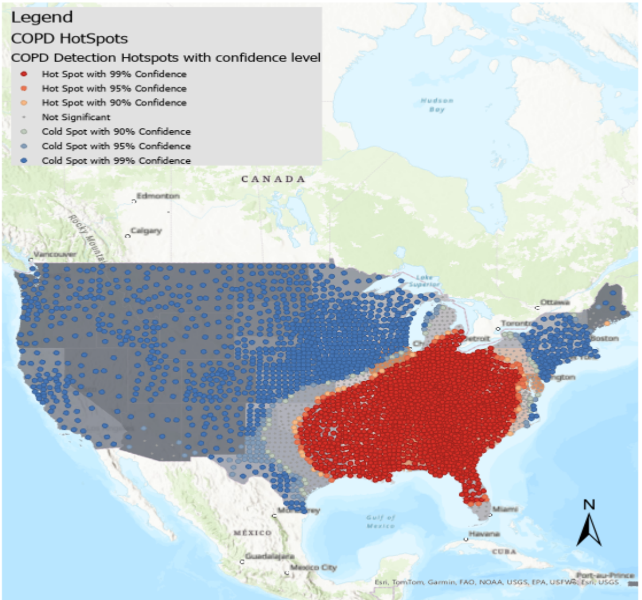

Figure 4: COPD Detection Hotspots in North America

6.5 Asthma Hotspots

The Asthma Detection Hotspots map (Figure 5) highlights significant asthma clusters in the eastern United States, particularly in the Appalachian region, Tennessee, and parts of Kentucky, similar to the patterns observed for lung cancer and COPD. These regions exhibit statistically significant hotspots with 99% confidence, where elevated PM 2.5 levels contribute to worsening asthma symptoms and heightening the overall disease burden.

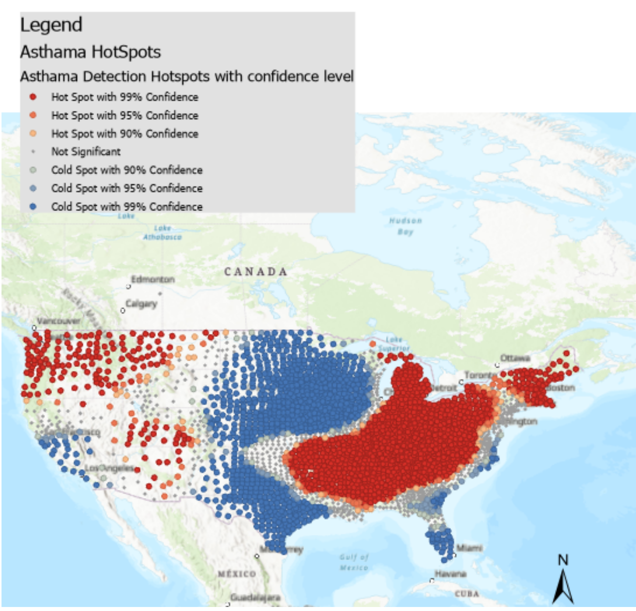

Figure 5: Asthama Detection Hotspots in North America

6.6 Population Vulnerability

The population map, focusing on dependent age groups (under 18 and over 65), reveals a high concentration of vulnerable populations in the Midwest and East Coast regions of the United States. These areas, particularly in states such as Kentucky, Ohio, Pennsylvania, and West Virginia, also correspond to regions with high PM 2.5 levels and significant clusters of respiratory diseases like asthma, COPD, and lung cancer.

In the Midwest and East Coast, the overlap between vulnerable population groups and elevated PM 2.5 concentrations suggests that socio-economic factors, such as age demographics, exacerbate the health impact of air pollution. The elderly and younger populations are more susceptible to respiratory diseases, and their concentration in regions with higher pollution levels places them at greater risk. This correlation indicates a need for targeted interventions in these densely populated areas to reduce pollution levels and address public health disparities related to air quality.

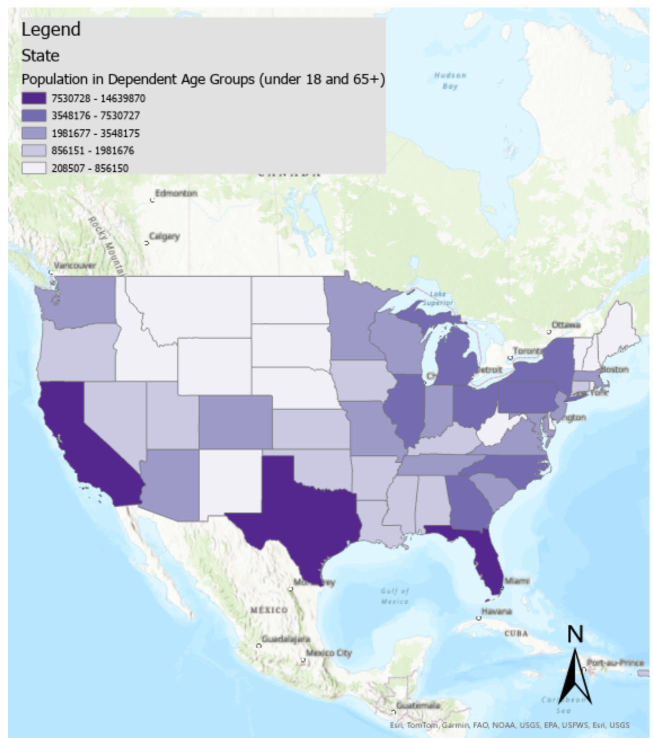

Figure 6: Population under 18 and 65+ in North America

7 SUMMARY AND CONCLUSIONS

The analysis of maps related to air quality, population demographics, and respiratory diseases shows a strong correlation between high PM 2.5 levels and increased rates of asthma, COPD, and lung cancer in the eastern and Midwestern United States. Regions like Ohio, Pennsylvania, and Kentucky, which experience elevated pollution levels, also have the highest disease rates.

The population map further highlights that areas with large numbers of vulnerable populations (under 18 and over 65) overlap with these disease hotspots, amplifying the health risks. In conclusion, the spatial alignment of high pollution levels with respiratory disease clusters underscores the need for targeted interventions and improved air quality regulations in these regions.

7.1 Key Findings

- PM 2.5 levels are concentrated in the eastern and Midwestern U.S., especially in Ohio, Pennsylvania, and Kentucky.
- Overlap of high PM 2.5 levels with asthma, COPD, and lung cancer hotspots.
- Regions with large dependent populations face heightened respiratory health risks.
- Strong link between pollution and respiratory diseases, emphasizing the need for intervention in the Midwest and East.

8 FUTURE WORK

Future research should aim to focus on identifying the key sources of PM 2.5 pollution, such as industrial activities and traffic emissions, to address the root causes. This will aid in creating targeted interventions to reduce air pollution and its health impacts in the affected regions. Additionally, studying the seasonal and long-term trends of pollution could provide further insights into mitigating its adverse effects.

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